

# **THE SWIFT PROJECT CONTAMINATION CONTROL PROGRAM: A CASE STUDY OF BALANCING COST, SCHEDULE AND RISK**

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## **ABSTRACT**

The Swift Observatory will be launched in early 2004 to examine the dynamic process of gamma ray burst (GRB) events. The multi-wavelength Observatory will study the GRB afterglow characteristics, which will help to answer fundamental questions about both the structure and the evolution of the universe. The Swift Observatory Contamination Control Program has been developed to aid in ensuring the success of the on-orbit performance of two of the primary instruments: the Ultraviolet and Optical Telescope (UVOT) and the X-Ray Telescope (XRT). During the design phase of the Observatory, the contamination control program evolved and trade studies were performed to assess the risk of contaminating the sensitive UVOT and XRT optics during both pre-launch testing and on-orbit operations, within the constraints of the overall program cost and schedule.

**KEYWORDS:** contamination, contamination control, Swift, Gamma Ray Burst, Ultraviolet and Optical Telescope, X-Ray Telescope, Burst Alert Telescope

## **INTRODUCTION**

For most major spacecraft missions, a contamination control program is instituted to ensure the successful on-orbit performance of contamination-sensitive instruments and subsystems. Contamination requirements are initially derived from mission and science requirements and then detailed contamination control measures are subsequently developed. The contamination controls are implemented throughout all project phases: instrument build (design, manufacture, integration, and test), spacecraft build (design, manufacture, integration, and test), instrument integration onto the spacecraft, integrated spacecraft mechanical and thermal environmental testing, transportation to the launch site, pre-launch and launch activities, and on-orbit operations.

For the Swift Observatory, a multi-wavelength Observatory, contamination controls were developed and instituted early in the program to help preserve the optical performance integrity of the Ultraviolet and Optical Telescope (UVOT) and X-Ray Telescope (XRT) during the telescope's integration and testing, integration onto the spacecraft, mechanical and thermal environmental testing of the Observatory (spacecraft with integrated telescopes), transportation to the launch site, launch activities, and on-orbit operations. Because the Swift Project was cost-constrained, numerous trade studies were performed to weigh the risk of contaminating the UVOT and XRT optics during pre-launch testing and on-orbit operations versus the cost and schedule impacts of implementing a strict contamination control program.

## **CONTAMINATION CONTROL PROGRAM**

A contamination control program must be designed to protect sensitive spacecraft and instrument components so that on-orbit performance goals may be achieved. Deposition of contaminants onto contamination-sensitive surfaces can cause instrument and/or system performance to degrade, detectors to malfunction, and ultimately may lead to system and/or detector failure. On-orbit, the deposition of contamination is difficult to detect, and usually is definitively determined only when the spacecraft is returned to Earth, or by an obvious lack of instrument response. With long-term programs such as the Hubble Space Telescope (HST), periodic calibration of instrument detectors has allowed indirect measurement of deposition levels on contamination-sensitive surfaces (optics and detectors) by comparing calibration data from year-to-year (Reference 1). Because contaminant deposition can cause science data to severely degrade, a preventative approach to controlling contamination starting at the study phase and continuing through the manufacture, integration, test, launch and on-orbit operations is recommended for contamination-sensitive spacecraft and instruments.

Contamination refers to molecular and particulate matter, which has the potential to degrade instrument or spacecraft performance. The presence of contaminants can interfere with and attenuate the field-of-view of optical instruments, or can cause deposition of a reflective and/or adsorbing layer on a contamination-sensitive surface, or can degrade the performance of thermal or attitude control subsystems. Contamination requirements define the allowable contamination levels or surface degradation which must not be exceeded during the fabrication, pre-launch, launch, and mission activities. These requirements are established for both thermal control performance (and other subsystems when necessary), optical, and detector performance.

To maintain contamination within budgeted levels, effective contamination control measures are employed during the design phase through on-orbit end-of-life. A contamination control plan is developed to document contamination requirements, program cleanliness level requirements, and contamination control measures.

### **Contamination Requirements**

To establish contamination requirements the following items must be considered: the contamination-critical components of each instrument, the sensitivity of each component to specific contaminants, and the mass deposition necessary to meet and/or exceed the specified accuracy limit of each instrument. The sensitive components of an instrument are found in three areas: thermal control surfaces, detectors, and optics. Depending on the type of component, the contaminants that are detrimental to one component's performance may not be detrimental to another component's performance.

For example, ultraviolet (UV) detectors are generally more sensitive to molecular deposition while infrared (IR) sensors are more sensitive to particulate contamination. On the other hand, most optical elements are sensitive to both molecular and particulate contamination depending on the wavelength of interest for the instrument. Thermal control surfaces are principally

sensitive to molecular contamination. However, depending on the ratio of solar absorptance to emittance ratios ( $\alpha/\epsilon$ ), particulates in large numbers may become detrimental to thermal control surface performance. The temperature of the contamination-sensitive surface also determines its vulnerability to certain contaminants. While a thin film of water on a surface may not change its optical properties, a thin film of ice would, in many cases, cause increased scattering (due to the scattering from the ice crystals), thus degrading the performance of the instrument.

Taking into account the optical properties of various materials and applying the design criteria for an instrument (which may be defined in a project's science and/or mission specifications), the contamination requirements can be established for each component of an instrument (thermal control surfaces, optics, and detectors). The allowable contamination requirements for optical and thermal surfaces, to specific contaminants, is typically established using lessons learned from previous missions, and available flight and experimental data. When the flight or experimental data is not available, the sensitivity determinations are augmented by a surface effects analysis.

### **Contamination Control Measures**

Contamination control measures include defining requirements for the environment, such as a cleanroom, where the majority of activities will occur. Contamination-sensitive projects typically use cleanrooms as a method of controlling the overall cleanliness environment surrounding the spacecraft for both molecular and particulate contamination. Molecular contamination can be further controlled by limiting the exposure of the optics to the ground environment, through the use of aperture doors, temporary covers or tents, and gaseous purges that limit deposition of airborne molecular contamination onto contamination-sensitive surfaces. Other contamination controls include double bagging the contamination-sensitive components (e.g. instrument or spacecraft) when they are exposed to uncontrolled environments (during mechanical and thermal environmental testing and transportation).

Most important to contamination-sensitive instruments is the selection of non-metallic materials, especially organic materials. Non-metallic materials will outgas when exposed to a vacuum environment. These outgassed products can then condense on contamination-sensitive surfaces (detectors, optics, etc.) which could cause degradation of the instrument performance. Generally, a materials screening criteria is established to give designers a general guideline for the choice of materials. For most contamination-sensitive instruments, the materials are screened using data obtained from ASTM E595 testing (Reference 2). The subsequent screening criteria are a total mass loss less (TML) than 1.0 percent and a collected volatile condensable material (CVCN) less than 0.1 percent. In addition to the ASTM E595 test, non-metallic materials can also be tested using ASTM E 1559 which provides data at different source and receptor temperatures and can be tailored to give results representative of the contamination-sensitive surfaces, for that particular mission (Reference 3).

Instruments which have stringent molecular contamination requirements (very low molecular contamination end-of-life levels, in the regime of a few angstroms of thickness) often require preprocessing in a vacuum environment to achieve acceptable on-orbit outgassing rates. This preprocessing in a vacuum environment is referred to as a "bakeout" with verification of the

target outgassing rate occurring at the end of the bakeout period (this period is referred to as the “certification phase”). Temperature Controlled Quartz Crystal Microbalances (TQCMs) are used to measure very small amounts of molecular deposition and verify the rate of deposition to the specific contamination-sensitive surface during the vacuum bakeout periods. Contamination control measures such as these described above and in References 1 and 4-8 reduce the risk of contaminating sensitive surfaces during the required mechanical and thermal testing, as well as reducing the available bulk materials outgassing during the on-orbit mission lifetime.

## **SWIFT MISSION**

The Swift Observatory’s design (shown in Figure 1) combines wide and narrow field-of-view instruments to allow prompt response to Gamma Ray Burst (GRB) events. Three (3) telescopes are mechanically integrated onto an Optical Bench which is then mechanically attached to the Spacecraft. This Optical Bench thermally isolates the telescopes from the Spacecraft, allowing for more uniform thermal control of the telescopes, independent of the orientation of the spacecraft. The wide-field Burst Alert Telescope (BAT) detects and images the GRB events. The spacecraft then automatically slews to point the narrow-field UVOT and XRT to determine the arc second position of the event and to observe the afterglow of the GRB event. In under 90 seconds, the Swift Observatory will detect a GRB, slew to observe the burst, resolve the arc second positioning of the burst, and relay this to a network of ground- and space-based telescopes.

The Swift Observatory was proposed and developed as “observatory-class science at a MIDEX cost”. To achieve the necessary cost savings, existing telescope and spacecraft designs were used. The UVOT was a “build to print” of the X-Ray Multi-Mirror (XMM) Optical Monitor. The design of the XRT took advantage of spare flight hardware from the JET-X mission.

### **Burst Alert Telescope**

The BAT instrument (see Figure 1) is designed to provide a large detector area to detect weak gamma-ray bursts and a large field-of-view to detect a large fraction of the bright gamma ray bursts. The BAT instrument uses currently available detector technology (borrowed from the medical field) and consists of a 5200cm<sup>2</sup> hard X-Ray detector plane positioned one meter away from a coded mask. The coded mask is comprised of a known pattern of randomly placed 5 x 5 x 1 mm lead tiles. The BAT extensively uses silicone-based materials to mount its detectors and coded mask.

### **Ultraviolet and Optical Telescope**

The UVOT instrument (see Figure 1) is a collaborative effort involving the Pennsylvania State University and the University College London, Mullard Space Sciences Laboratory (United Kingdom) to produce ultraviolet and optical low-resolution spectra of bright GRBs and broad-band photometry over the range of 170 to 650 nm. The UVOT is a Ritchey-Chretien telescope which operates as a photon-counting instrument by using micro-channel plate intensified CCD detectors. The primary science requirement is to rapidly integrate and generate a ‘finding chart’

(within 0.3 arc seconds position for the burst and the field of stars close to the gamma ray burst location) and then to transmit the chart to other ground- and space-based telescopes.

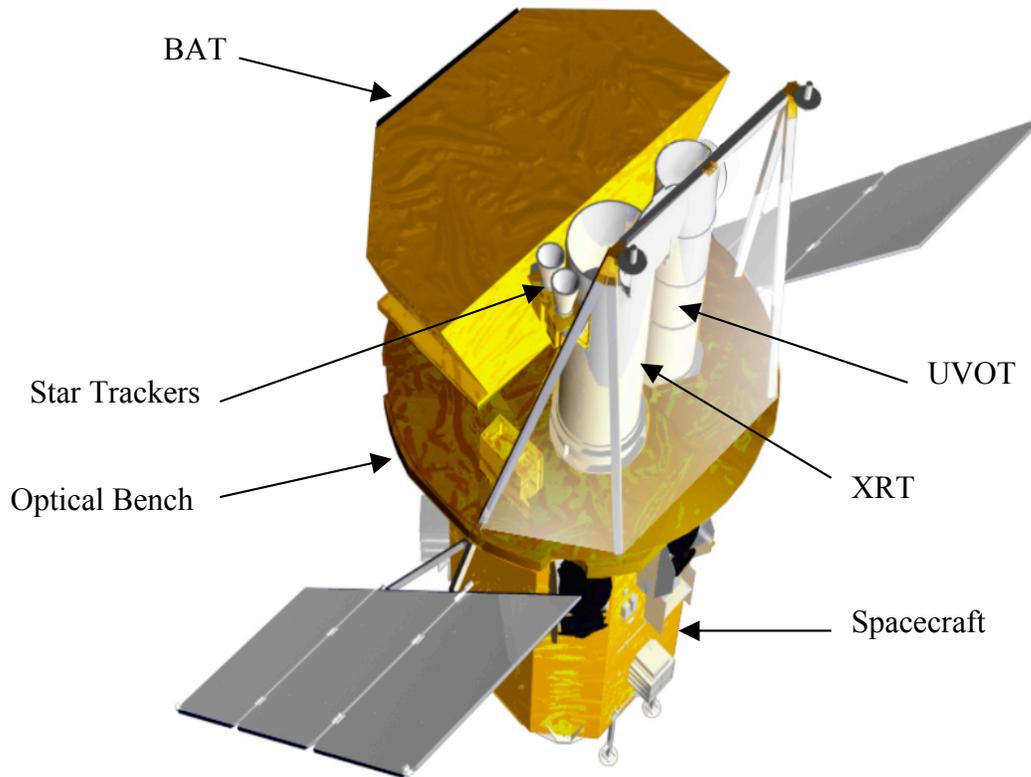


Figure 1. The Swift Observatory

### **X-Ray Telescope**

The XRT instrument (see Figure 1) is a collaborative effort among the Pennsylvania State University, the University of Leicester (United Kingdom), and the Osservatorio Astronomico di Brera (Italy), to produce a sensitive, autonomous X-Ray Charge Coupled Device (CCD) imaging spectrometer. The XRT is designed to measure the flux, spectrum, and light curve of GRBs and afterglow over the range of 0.2 to 10 keV. The XRT uses a nested grazing incidence Wolter I telescope unit to focus X-rays onto a state-of-the-art CCD. The XRT primary science requirement is to rapidly determine the position of the GRB within 2.5 arc seconds.

### **SWIFT PROGRAM MANAGEMENT**

The Swift Project is managed by the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. For over 40 years, the

NASA/GSFC has had a long history of producing state-of-the-art spacecraft and instruments. It is within this culture of producing cutting-edge, high-performance spacecraft and instruments that the Swift Contamination Control Program was developed. Overall, the NASA/GSFC technical culture is based on a risk-averse design strategy. That is, from a technical viewpoint, most mechanical and thermal designs have been conservatively designed – they have had large performance and safety margins and multiple redundant systems to avoid performance or mission failure.

In the 1990's, with the advent of NASA's "cheaper, better, faster" management approach the NASA/GSFC design philosophy became more in-line with developing designs that meet the mission requirements with tolerable margins and higher risk. While this has not been an easy transition, the NASA/GSFC culture has embraced the concept of increased risk of failure with decreased design margins in order to reduce overall mission costs.

During the manufacture and build of the Swift Observatory systems (instruments and spacecraft), the Project was supported with a small management team at NASA/GSFC. The Swift Project was unique in that the major industry and university partners performed their integration and test activities at NASA/GSFC facilities. While this reduced program risk, it required an integrated industry-university-government team to work together to carryout and meet all requirements.

The Swift Program followed the standard NASA/GSFC review process to independently review the Observatory design at several major milestones – Science Requirement Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR), Pre-ship (pre-delivery) Review (PSR), Pre-environmental Test Review (PER), Pre-ship Review for the launch site activities, and Launch Readiness Review (LRR). These reviews were also conducted for the Observatory systems (e.g. Spacecraft, BAT, UVOT, and XRT), when applicable.

## **SWIFT CONTAMINATION CONTROL PROGRAM**

The Swift Observatory Contamination Control Program evolved during the design phase of the Observatory. Trade studies were performed to evaluate the risk of contaminating the sensitive UVOT and XRT optics both during pre-launch testing and on-orbit operations, compared to the constraints of the overall program cost and schedule requirements.

After the XRT and UVOT PDRs it was obvious that these instruments required stringent contamination controls to meet their end-of-life performance requirements. In fact, the XRT and UVOT contamination levels required to meet the on-orbit mission science requirements (see Table 1) became the primary drivers for the overall Observatory contamination control program.

Due to exposure during launch, the Star Trackers' on-orbit contamination requirements were an additional driver for the launch site and launch vehicle contamination control program. As shown in Figure 2, these contamination requirements were then flowed down to the less contamination-sensitive hardware (BAT, solar arrays, electronics boxes, etc.).

Table 1. Swift Contamination-Sensitive Surfaces End-of Life Contamination Requirements

Telescope Sensitive Surfaces			
Telescope	Surface	Contamination Requirement*	
		Particle Level	Molecular Level
Ultraviolet and Optical Telescope (UVOT)	Optical Surfaces	300	B <sup>+</sup>
	Detectors	300	B
	Aperture Door	400	B
	Radiator	400	B
	MLI	400	B
X-Ray Telescope (XRT)	Mirrors	300	B
	Focal Plane Camera	300	A
	Aperture Door	400	B
	Radiator	400	B
	MLI	400	B
Burst Alert Telescope (BAT)	Detectors	VC-HS	NA
	Mask	VC-HS	NA
	Graded-Z Shield	VC-HS	NA
	MLI	VC-HS	NA
	Adsorber Assembly	400	B
	Contamination Enclosure	400	B
Spacecraft Surfaces			
Location	Surface	Contamination Requirement*	
		Particle Level	Molecular Level
XRT	Star Trackers	400	A
Optical Bench	IRUs	400	B
Optical Bench	Sun Shade	400	B
Spacecraft	Battery Radiator	400	B
	Solar Arrays	400	B

\* per MIL-STD 1246

<sup>+</sup> B = 2.0 mg/0.1m<sup>2</sup> or 200 Å; A = 1.0 mg/0.1 m<sup>2</sup> or 100 Å

VC-HS – visibly clean highly sensitive per JSC-SN-C-0005 (See Reference 10)

NA – Not applicable

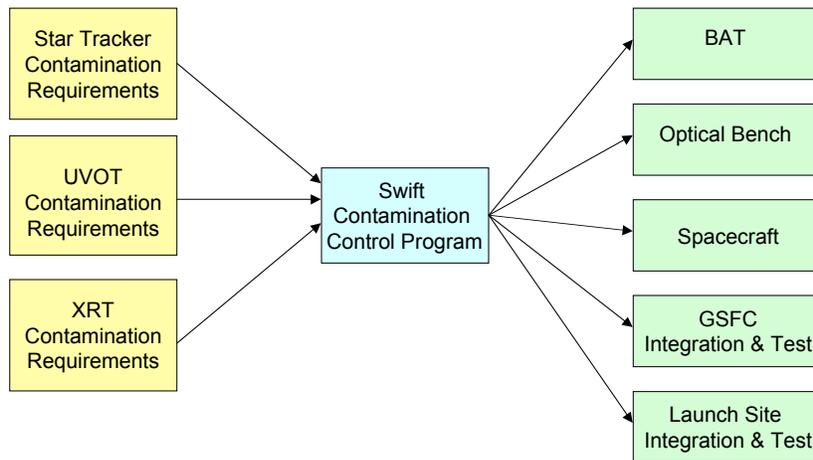


Figure 2. Contamination Requirements Flow-Down of Contamination-Sensitive Instruments

## Trade Studies

As with most contamination control programs, trade studies were performed to determine acceptable outgassing rates for XRT and UVOT (self-contamination) and all other instrument and spacecraft hardware so that XRT and UVOT would not exceed their end-of-life molecular deposition levels. Several of the major trade studies are discussed herein for both on-orbit operations and ground testing phases.

## MISSION OPERATIONS

The automated nature of the spacecraft contributed additional complexity to the on-orbit mission operations. To prevent inadvertent exposure of the UVOT or XRT optics to bright objects (e.g. Sun, Moon, Earth) two options were considered: the addition of a sunshade or the addition of aperture doors that could be commanded closed/open. Data from the HST Wide Field Planetary Camera I (WFPC I) suggested that long-term exposure to bright objects (even previously considered “non-bright” objects, such as the Earth) could in fact cause molecular deposition to photopolymerize and cause deleterious reflectance loss at ultraviolet wavelengths (Reference 9). Because of the rapid-response of the mission (spacecraft slewing, resolution of the burst and arc second pointing resolution) the UVOT and XRT had mission requirements that required higher resolution, which, in turn made it necessary for even more rigidity on the contamination requirements. Due to cost and increased risk on-orbit (failure of door to re-open) the project decided to request that the design of the Observatory include a sunshade which would provide a 40° keep-out zone to the UVOT and XRT.

## ON-ORBIT OUTGASSING

A trade study was performed to determine how to limit on-orbit outgassing from the BAT instrument to the contamination-sensitive UVOT and XRT surfaces. Due to the large amounts of silicone-based materials used in bonding the coded mask and detector array, BAT would be the largest on-orbit contamination source to the XRT and UVOT. It is well known that outgassed silicone materials are highly adsorbing in the ultraviolet wavelength range and would significantly affect the on-orbit performance of the UVOT. Ultimately, two potential solutions were compared: to vacuum bake the BAT instrument prior to integration onto the spacecraft, until it achieved acceptable on-orbit outgassing rates; or to incorporate innovative contamination-control technology (molecular adsorbers) into the BAT mechanical design to limit the outgassing from the BAT. The bakeout option was costly and would have a significant schedule impact since the BAT would need to be preprocessed in a vacuum environment for a significant amount of time (60-90 days was estimated).

The other option was also fully considered. This option was to utilize innovative contamination control technology, in the form of placing molecular adsorbers onto the BAT at critical locations. Molecular adsorbers are a new type of “contaminant capture” device which works by bonding with outgassed species by a chemisorption process. For the BAT instrument, the outgassed species would be primarily from the extensively used silicone materials. Trapping these outgassed species will render the BAT instrument a “good neighbor” to the UVOT and XRT instruments (additional detailed information on adsorbers can be found in Reference 8). The Project opted to incorporate the new contamination-control technology (molecular adsorbers) combined with designing a contamination enclosure to provide a controlled vent path for the BAT instrument. This design concept was tested early in the program to further reduce risk and to verify that the contamination enclosure could be designed to be “molecule tight” and force all venting of the BAT volume to occur through the molecular adsorbers, thus trapping the deleterious outgassed silicone species.

A trade study was performed to assess if adding molecular adsorbers, identical to those described in Reference 8 (used on the HST program) would add enough margin to the UVOT end-of-life molecular contamination requirements. The UVOT is a “build to print” duplicate of the X-Ray Multi-Mirror (XMM) Optical Monitor. This Optical Monitor was designed to be compact and had the electronics modules directly behind the optical cavity, which provided the primary vent path for the instrument. For UVOT, these electronics modules could potentially be a primary source of self-contamination for the UVOT optics and detectors. One solution to add additional margin to the UVOT molecular contamination requirements would be to vent the electronics modules out the back of the telescope (away from the optics cavity). This design change could not be accommodated, however, molecular adsorbers, which act as virtual vents were able to be incorporated into the design (near or on the electronics modules) to trap outgassed material prior to entering the optics cavity. The addition of the molecular adsorbers increased the effective vent area by about an order-of-magnitude, which decreased the predicted molecular contamination levels on the optics and detectors to within acceptable limits.

Several trade studies were performed to assess whether the Spacecraft needed to be baked out to reduce its on-orbit outgassing levels to preclude contaminating sensitive optical or thermal

surfaces. First, the outgassing effect from the Spacecraft and Spacecraft components in close proximity to the UVOT and XRT were assessed. Detailed molecular mass transport modeling analyses were performed for the Swift mission to determine the expected deposition levels on critical surfaces (UVOT and XRT optical surfaces, Star Tracker contamination-sensitive surfaces, and all radiator surfaces), at various points in the mission, and to identify possible major threats to UVOT and XRT performance success. Based on these analyses, it was determined that due to the Observatory design, the only Spacecraft components that were a contamination threat to UVOT and XRT were the Solar Arrays and those Spacecraft components located in close proximity to the UVOT and XRT (Star Trackers, Antennas, Sun Sensors, and respective electrical cabling). It was determined that these spacecraft components would undergo a vacuum bakeout to reduce their outgassing rates to acceptable levels.

Another trade study was performed to assess the impact of overall spacecraft outgassing on the contamination-sensitive radiator surfaces. One of the solutions included a more comprehensive bakeout of the Spacecraft including all system hardware (electrical boxes, gyros, batteries, etc.) to achieve a lower outgassing rate. A non-bakeout option was also assessed using detailed molecular mass transport modeling analyses to determine if a venting scheme could be implemented that would achieve the desired result, instead of the costly and time consuming bakeout option. Of interest were the radiators on electronics boxes and the XRT detector radiator. Because of their thermal designs, deposition of outgassed materials onto these contamination-sensitive radiators, especially the electronics boxes, combined with exposure to the Sun (during slews) could cause significant degradation of the radiator thermal properties. Degraded thermal properties could in turn affect the UVOT and XRT duty cycles, thus impacting the mission.

It was determined that sealing the spacecraft thermal blankets, to route all outgassed materials under the blankets to a controlled vent (away from the contamination-sensitive radiator surfaces) would ameliorate the contamination risk, reduce program cost, and preserve the program schedule (the spacecraft would not have to undergo an approximately 30-day vacuum bakeout). The Spacecraft thermal blankets were designed and integrated onto the Spacecraft so that there would be two (2) controlled vents. These vents were located near the top of the Spacecraft (under the Optical Bench) away from sensitive radiator surfaces. It was predicted that the subsequent deposition on the contamination-sensitive radiator surfaces would be negligible over the mission life.

A trade study to determine the contamination budgets for the UVOT and XRT instruments was also performed. The UVOT and XRT contamination budgets were negotiated with the Swift Project and the respective telescope integrators. It was determined that the on-orbit portion of the molecular contamination would be set at 100Å for both UVOT and XRT. For the Star Trackers it was determined to be 50 Å. These levels were roughly half of the total deposition allowed at end-of-life. By restructuring and preserving the contamination budget, the Swift Project decreased the risk of an on-orbit contamination event becoming life-limiting for little, if any, additional cost or schedule impacts. The UVOT and XRT were delivered to the Spacecraft for integration with their measured contamination deposition levels significantly less than that budgeted for the instrument integration and test phases. These levels were approximately 10 percent of the budgeted level. During the Observatory integration and test program it was

planned that the UVOT and XRT optical surfaces and detectors would be exposed for a short period (approximately 30 minutes) in the cleanroom during the aperture door-opening test. It was anticipated that this test would not significantly raise the deposition levels on the optical surfaces due to the controlled environment.

## GROUND TESTING

Mission-unique contamination controls have been planned for the thermal environmental testing. Although the on-orbit deposition levels from the Spacecraft to the UVOT and XRT surfaces are predicted to be negligible, during the thermal environmental testing, deposition from outgassing spacecraft components can be a significant threat due to the chamber walls reflecting and/or desorbing the outgassed material during the hot portions of the test. The final trade study was performed to determine if the Spacecraft needed to be baked out to reduce its outgassing rate and preclude contaminating the UVOT and XRT contamination-sensitive surfaces during the thermal environmental testing. A non-bakeout option of enclosing the sensitive portion of the Observatory was also assessed (as opposed to on-orbit, as in earlier analyses). These contamination enclosures are typically used for much smaller flight hardware (instruments), but the concept could be scaled-up for the Swift observatory test.

To reduce the risk of a contamination event, reduce cost, and preserve schedule, a contamination enclosure will be used to isolate the UVOT, XRT, Star Trackers, and critical radiator surfaces from the chamber walls and thus prevent the outgassed material from the Spacecraft depositing on these contamination-sensitive surfaces. This enclosure is shown in Figure 3. The enclosure will be primarily comprised of 1-layer aluminized Mylar and cold plates with two (2) controlled vent ports viewing scavenger plates.

In addition to the contamination enclosure, scavenger plates (shown in Figure3), running at liquid Nitrogen temperatures, will be used to trap outgassed materials from the Spacecraft, the contamination enclosure, and near the XRT vent port. These scavenger plates will be run cold throughout the test and will remain cold while the chamber walls are warmed in preparation for the chamber back-fill. Once the chamber walls are warm, the scavenger plates will be warmed to about  $-50^{\circ}\text{C}$  for the back-fill operations. When the pressure in the chamber is about 600 torr, the scavenger plates will be warmed again to about  $-10$  to  $0^{\circ}\text{C}$ . Once the chamber door is opened, the UVOT and XRT gaseous Nitrogen purge will be reestablished. The scavenger plates will then be warmed to room temperature. The collected material on the scavenger plates is not volatile at pressures above 600 torr and will not re-evaporate and present a contamination hazard to the Swift Observatory during the post-test electrical testing and de-integration from the test fixtures.

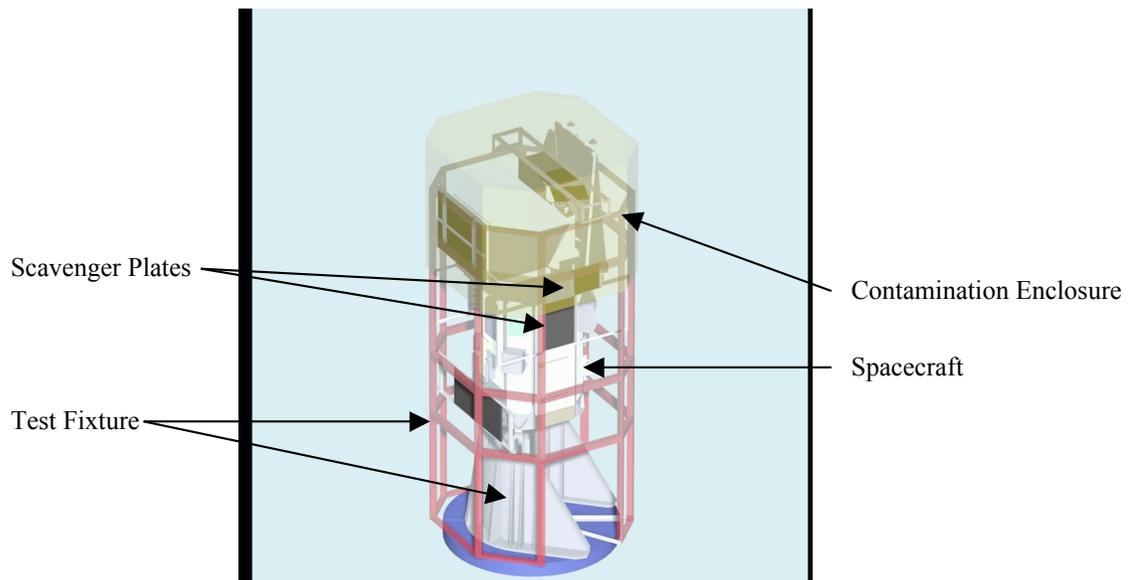


Figure 3. The Thermal Vacuum Test Contamination Enclosure

## DISCUSSION

The Swift Project has taken advantage of the “lesson learned” at NASA/GSFC from previous missions such as the Hubble Space Telescope. Numerous trade studies were performed to determine if the traditional conservative approach (for example, baking all components on a contamination-sensitive mission) was the only option to achieve on-orbit mission performance requirements. By embracing a managed risk approach, the Swift Project has been able to reduce the cost of their Contamination Control Program by roughly, an order-of-magnitude. Typically the cost of Contamination Control Program to achieve science performance similar to UVOT and XRT has cost approximately 10 percent of the total overall program budget. However for the Swift Program, this has been reduced to about 1-2 percent of the total overall budget. This is a considerable cost savings.

Several unique contamination control options were considered for the Swift Observatory such as the incorporation of molecular adsorbers, which precluded the need for extensive bakeouts. Other design changes such as sealing the Spacecraft thermal blankets and venting the outgassed material in a controlled manner eliminated the requirement for the Spacecraft to be baked out to reduce on-orbit outgassing-rates. Only those components, which would directly impinge on (had direct line of sight to) the UVOT or XRT contamination-sensitive surfaces, were baked out. thus reducing the risk of an on-orbit contamination event, while saving program costs, and schedule.

NASA/GSFC has a long history of testing contamination-sensitive spacecraft and instruments in a thermal-vacuum environment. The Swift Project has taken advantage of this historical data to choose a low-risk, low-cost option of using a contamination enclosure to protect the

contamination-sensitive components of the Swift Observatory during the thermal-vacuum test. This is a low-risk option that precludes baking the Spacecraft (cost savings and no schedule impact) while maintaining the stringent contamination requirements of the UVOT, XRT and Star Trackers.

## **SUMMARY**

The Swift Project Contamination Control Program utilized trade studies to compare the risk of potentially contaminating the sensitive UVOT, XRT, and Star Tracker optics both during pre-launch testing and on-orbit operations, versus consuming valuable program budget dollars and schedule time. Trade studies assessing both the BAT instrument and Spacecraft produced unique solutions that resulted in non-bakeout alternatives being implemented to control on-orbit outgassing to the UVOT, XRT, and Star Trackers. These innovative solutions were less costly than the traditional bakeout programs, but still resulted in the desired effect of reducing the risk of on-orbit contamination from these sources. As an additional benefit, the mission schedule was not impacted and integration activities could proceed as planned.

NASA/GSFC has been successful in furthering the field of Contamination Engineering by designing, testing, analyzing and ultimately incorporating new contamination control measures into a number of recent and upcoming spacecraft programs. These new techniques have thus far, proven to be functionally effective, while saving space missions significant dollar and schedule resources.

As new methods continue to be developed and demonstrated, Contamination Control Programs can be more effectively tailored to fit specific spacecraft and instrument needs. The goal is to design and implement Contamination Control Programs which achieve the desired result – mission performance success – while limiting cost and schedule impacts.

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# The Swift Project Contamination Control Program: A Case Study of Balancing Cost, Schedule and Risk

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# Overview

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- Background
  - Contamination Control Program
  - Contamination Requirements
  - Contamination Control Measures
- Swift
  - Mission
  - Contamination Control Program
  - Trade Studies
- Discussion
- Summary



# Background

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- Contamination Control Programs are instituted to ensure on-orbit performance of contamination-sensitive instruments and subsystems
- Contamination
  - molecular: deposition of reflective and/or adsorbing layer
  - particulate: increased scattering
- Contamination requirements
  - define allowable contamination levels or surface degradation for all project phases
  - derived from mission and science requirements
  - established for thermal control, optical and detector performance



# Background

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- Contamination control measures
  - developed to maintain contamination within budgeted levels
  - implemented throughout all project phases:
    - design and build
    - integration
    - mechanical and thermal environmental testing
    - transportation
    - pre-launch and launch activities
    - on-orbit operations
  - defined environmental requirements: cleanrooms, bagging, purges
  - defined allowable non-metallic materials
  - defined acceptable on-orbit outgassing rates and required vacuum preprocessing or conditioning (bakeouts)

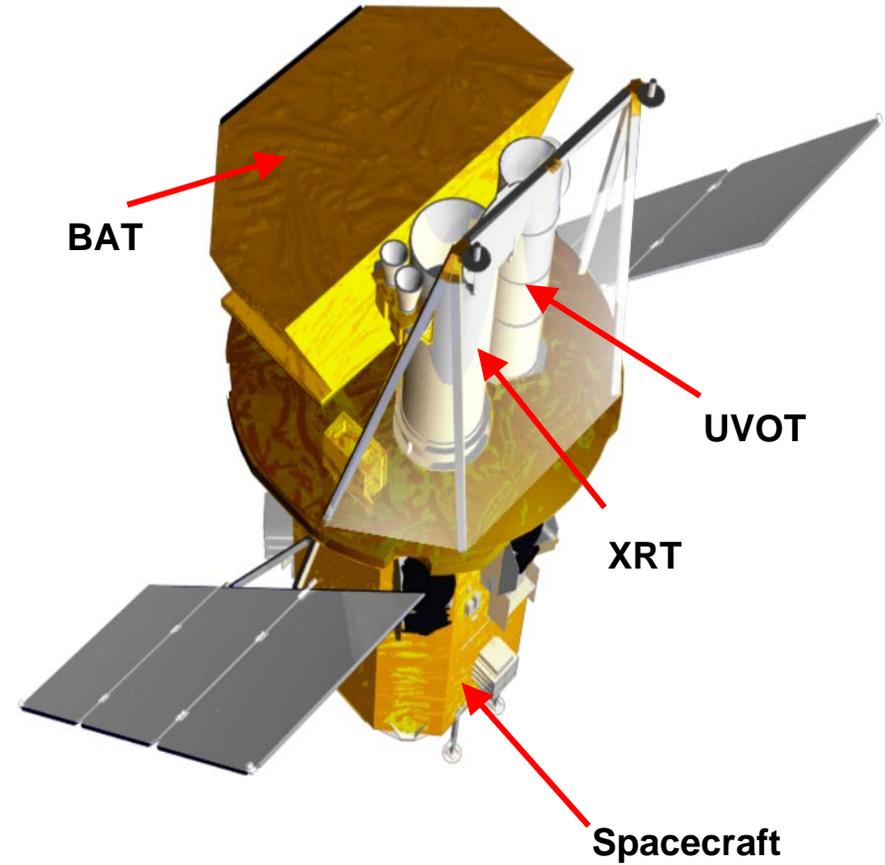


# Gowning Requirements





# Swift Observatory





# Swift Mission

- Three telescopes provide rapid detection of the Gamma Ray Burst (GRB) and transmission of location
  - Burst Alert Telescope (BAT): detects bright GRBs
  - X-ray Telescope (XRT): rapidly determines the position of the GRB
  - Ultraviolet and Optical Telescope (UVOT): rapidly generates “finding chart” and transmits the chart to other ground- and space-based telescopes
- Spacecraft (SC) provides autonomous slewing for rapid detection, verification, and transmission of GRB event



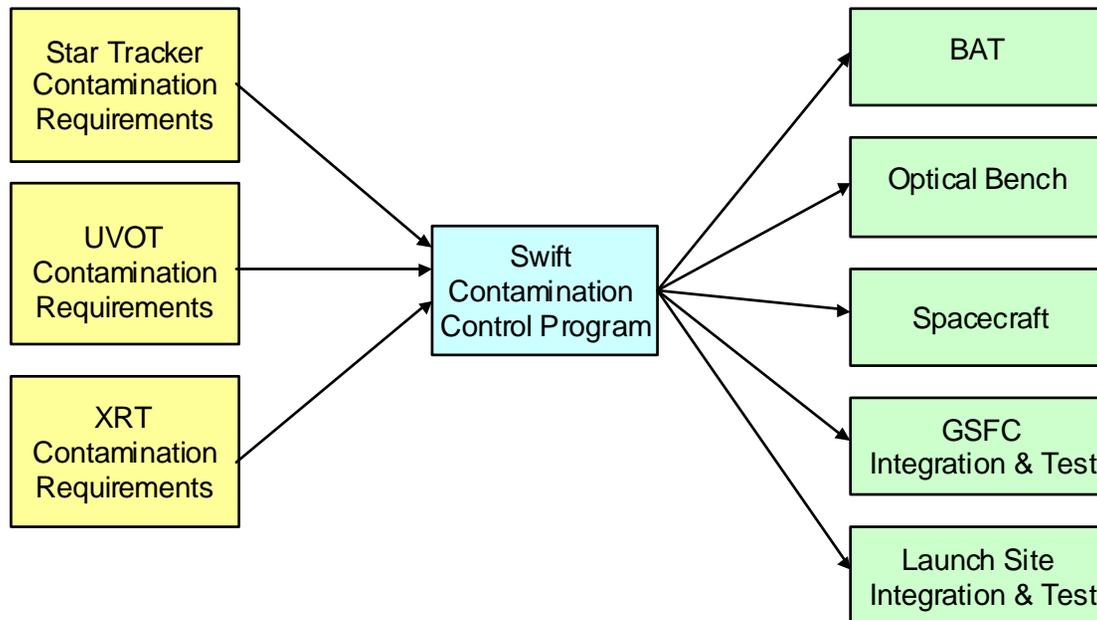
# Swift Contamination Control Program

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- Derived to maintain the Star Tracker, XRT and UVOT stringent contamination control requirements
  - Star Tracker
    - sensitive to particulates and molecular deposition
  - XRT
    - sensitive to particulates and molecular deposition
    - radiator: painted - no touch surface
  - UVOT
    - sensitive to particulates and molecular deposition
    - radiator: painted - no touch surface



# Requirements Flow-Down





# Contamination Control Measures

- Contamination Control Measures: control exposure to deleterious environments
  - Star Tracker
    - aperture covered until last access prior to launch
  - XRT
    - aperture door closed during all pre-launch Observatory activities
    - continuous gaseous Nitrogen purge required
    - radiator: covered until last access prior to launch
  - UVOT
    - aperture door closed during all pre-launch Observatory activities
    - continuous gaseous Nitrogen purge required
    - radiator: covered until last access prior to launch



# Trade Studies

<u>Trade Study</u>	<u>Reduced Cost</u>	<u>Preserved Schedule</u>	<u>Reduced Risk</u>
Mission Operations			
Sunshade	X	NA	X
On-orbit Outgassing			
BAT Vacuum Conditioning	NA	NA	X
BAT Molecular Adsorbers	X	X	X
UVOT Molecular Adsorbers	NA	X	X
SC Component Vacuum Conditioning	NA	X	X
SC Bus Vacuum Conditioning	X	X	X
SC Controlled Venting	X	X	X
UVOT and XRT Contamination Budgets	NA	NA	X
Ground Testing			
Contamination Enclosure	X	X	X



# Mission Operations

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- Concern: inadvertent exposure of the UVOT or XRT optics to bright objects (Sun, Moon, Earth)
- Contamination effect: photopolymerization of molecular deposition which causes deleterious reflectance losses at ultraviolet wavelengths
- Options: addition of sunshade (40° keep-out zone) or reusable aperture doors
- Sunshade least risk and cost => implemented sunshade



# On-orbit Outgassing

- Concern: deposition of outgassed materials from the BAT to contamination-sensitive surfaces
- Contamination effect: outgassed materials could deposit on the UVOT and XRT contamination-sensitive surfaces (mirrors) causing deleterious reflectance losses at ultraviolet wavelengths
- Options: vacuum condition the BAT instrument to achieve acceptable outgassing rates or trap the outgassed materials at the BAT vents using molecular adsorbers
- Molecular Adsorbers least cost, schedule, and risk => incorporated molecular adsorbers into design



# On-orbit Outgassing

- Concern: UVOT self-contamination would exceed on-orbit requirements
- Contamination effect: UVOT design required the electronics, located behind the optics cavity, to vent through the optics cavity causing deposition of UV-adsorbing material onto contamination-sensitive surfaces (mirrors, filters, detectors)
- Options: add a vent to the electronics cavity or create “virtual vents” using molecular adsorbers to trap outgassed materials within the electronics cavity
- Molecular Adsorbers least cost, schedule, and risk => incorporated molecular adsorbers into design



# On-orbit Outgassing

- Concern: Spacecraft could contaminate optics
- Contamination effect: Spacecraft outgassed materials could deposit on Star Tracker, UVOT and XRT contamination-sensitive surfaces (mirrors) causing deleterious reflectance losses at ultraviolet wavelengths
- Options: vacuum condition (bakeout) Spacecraft components which have a direct line-of-sight to the Star Tracker, UVOT or XRT apertures or bakeout entire Spacecraft
- Component Bakeout was least cost, schedule, and risk => baked Solar Arrays, Sunshade, Antennas, cabling, etc.



# On-orbit Outgassing

- Concern: Spacecraft could contaminate thermal surfaces
- Contamination effect: Spacecraft outgassed materials could deposit on BAT and XRT radiators causing increased solar absorptance ( $\alpha$ ) and loss of detector cooling
- Options: vacuum condition (bakeout) Spacecraft components which have a direct line-of-sight to the thermal surfaces or design a controlled venting path
- Controlled vent path was least cost, schedule, and risk => thermal blankets were sealed so that all Spacecraft boxes vent to top of Spacecraft on  $\pm Y$  sides



# On-orbit Outgassing

- Concern: XRT and UVOT contamination budget allocations would not provide adequate margin for the on-orbit operations phase
- Contamination effect: life-limiting if self-contamination or on-orbit contamination from other sources exceeded the overall contamination budget
- Options: allow instruments to determine on-orbit allocation or Project dictate on-orbit allocation
- Project determined on-orbit allocation was least cost, schedule and risk => Project preserved 50% of total contamination budget allocation for on-orbit operations



# Ground Testing

- Concern: Spacecraft could contaminate the Star Trackers, UVOT and XRT during the thermal vacuum test due to the accumulation of contaminants on the (cold) chamber walls
- Contamination effect: material could deposit on BAT, UVOT and XRT surfaces and radiators causing increased solar absorptance ( $\alpha$ ) and loss of detector cooling and/or reemit to optical surfaces
- Options: vacuum condition the Spacecraft to meet acceptable outgassing rates or isolate the instruments within a contamination enclosure
- Contamination enclosure was least cost, schedule and risk => implement contamination enclosure



# Discussion

- Implemented “lessons learned” from other NASA/GSFC programs (Hubble Space Telescope)
- Used a managed-risk approach
  - weighed traditional conservative approach (vacuum conditioning all components to achieve on-orbit outgassing requirements) against innovative design choices to achieve the same result
  - determined early in program contamination requirements needed to meet mission and science requirements (goals versus requirements)
- Reduced cost of the total overall contamination control budget from approximately 10% of total overall program budget to approximately 1-2% of the total overall program budget



# Summary

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- Swift Contamination Control Program utilized trade studies to compare risk of contaminating a sensitive surface versus cost and schedule
- Design changes which mitigated vacuum conditioning were less costly while preserving the on-orbit contamination budgets
- Swift Contamination Control Program managed risk while maintaining the contamination levels required for mission performance and while preserving program budget and schedule